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USAAVLABS TECHNICAL REPORT 66-29

IMPACT TEST METHODS AND RETENTION HARNESS CRITERIA FOR U. S. ARMY AIRCREWMAN PROTECTIVE HEADGEAR

By

Joseph L. Haley, Jr.
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March 1966

U. S. ARMY AVIATION MATERIEL LABORATORIES
FORT EUSTIS, VIRGINIA

CONTRACT DA 44-177-AMC-254(T)

AVIATION SAFETY ENGINEERING AND RESEARCH
A DIVISION OF FLIGHT SAFETY FOUNDATION, INC.
PHOENIX, ARIZONA

U S ARMY MATERIEL COMMAND

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This report was prepared by Aviation Safety Engineering and Research (AvSER), a division of the Flight Safety Foundation, Inc., under the terms of Contract DA 44-177-AMC-254(T). This effort consisted of the investigation of impact test methods and retention harness criteria for U. S. Army aircrewman protective headgear. It is a follow-on study which was initiated by the U. S. Army Natick Laboratories, Natick, Massachusetts.

The conclusions and recommendations contained herein are concurred in by this command.

Task 1P125901A14230
Contract DA 44-177-AMC-254(T)
USAAVLABS Technical Report 66-29
March 1966

IMPACT TEST METHODS AND RETENTION HARNESS CRITERIA FOR U. S. ARMY AIRCREWMAN PROTECTIVE HEADGEAR

Technical Report
AvSER 65-15

by

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SUMMARY

This report discusses impact test methods and helmet retention harnesses for U. S. Army aircrew protective helmets. On the basis of simple analyses and some experimental testing, recommendations are made for the design and testing of helmet retention harnesses. A "collar-type" retention harness is recommended, and two tests are suggested as a method of insuring a good design.

Impact tests were conducted by an impactor-drop method and a headform drop method. These test methods employ one movable piece and one fixed piece rather than two movable pieces as are currently used by most test agencies. On the basis of the impact test results, it is recommended that the impactor-drop method be used for the qualification of U. S. Army aircrew helmets. Probable head impact velocities and impact surfaces are discussed, and impact test conditions are specified.

Some of the recommendations made in this report are based upon conclusions reached in a previous study, USAAVLABS Technical Report 65-44, conducted under U. S. Army Contract DA 44-177-AMC-254(T).

FOREWORD

This report provides the necessary impact and testing data for use in writing a military specification on helmet retention criteria and impact test methods. Some of these data were developed under provisions of previous contracts DA 44-177-AMC-116(T) and DA 44-177-AMC-254(T) with the U. S. Army Aviation Materiel Laboratories*, Fort Eustis, Virginia, and the results have been published in Reference 2.

Grateful appreciation is extended to Professor L. M. Patrick and staff of the Biomechanics Research Center at Wayne State University, Detroit, Michigan, for their time and the use of their facilities in conducting the helmet retention harness tests on a cadaver. These tests were conducted at no cost to this contract other than the travel expenses and the materials used in the test.

Acknowledgement also goes to Mr. Gerrit J. Walhout of the Aviation Safety Engineering and Research (AvSER) staff for the analysis of the data on the retention harness tests.

*Formerly U. S. Army Transportation Research Command

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TABLE OF CONTENTS

ILLUSTRATIONS

INTRODUCTION

Although a considerable amount of research effort could be devoted to the area of basic research on head protection, it appears that the most fruitful results will be obtained by careful attention to (1) the decelerative limits for the head when protected by a helmet, with emphasis being placed on the unconsciousness, fracture, and lethal thresholds, and (2) the problem of helmet retention.

Additional developmental work on helmets must still be done before a production aircrew helmet is available which will reasonably meet all the desirable protective characteristics. Further helmet development can probably best be accomplished by helmet manufacturers because economic as well as crash protective factors are involved.

This study is limited to helmet retention harness analysis and impact test methods. Although the retention harness problem and impact test methods may not affect impact protection directly, they certainly have a decided indirect effect upon it. It is obvious that a retention harness must keep the helmet on the head during impact; it should also be obvious that the proper proof testing of helmets is just as important as design criteria to insure that the end product provides optimum protection.

RETENTION HARNESS ANALYSIS

BACKGROUND

Aircraft accident experience indicates that protective helmets are often lost in crashes. One study of U. S. Army aircraft accidents showed that out of 100 crew members involved in crashes while wearing helmets, 24 of these individuals lost their helmets during the crash sequence (Reference 1). Another study of severe accidents resulting in head injuries indicated that 45 percent of the subjects (13 out of 29) lost their helmets during the accident (Reference 2). These statistics clearly show that helmet retention needs improvement.

APPROACH TO THE PROBLEM

The frequent loss of helmets during accidents is a matter of record. Little information, however, is available on the cause of helmet loss. It appears that helmets are lost in accidents by either of two methods: (1) the helmet is removed by its own inertia force, that is, the weight of the helmet itself may be enough to cause removal from the occupant's head at occupant acceleration levels of 10G or more; or (2) the helmet is removed by an external impact with environmental structure, that is, the helmet can be struck tangentially near its periphery as the occupant's body is thrown forward and downward so that the chin strap is broken and the helmet is removed, as illustrated in Figure 1. This sketch is based upon an actual accident case, the details of which are recorded in Reference 5.

Figure 1. Artist's Sketch Illustrating How a Helmet Can Be Removed by Impact with Cockpit Structure.

A helmet cannot be removed by external impacts if a properly designed and fitted retention harness is used, unless the magnitude of the impact is large enough to break the helmet retention system. Although no published information can be located on the required strength of helmet retention systems, Dr. George Snively of the Snell Foundation, Sacramento, California, observed during a recent symposium (Reference 3) that helmets have been torn from racing car drivers in crashes because of broken chin straps without causing injury to the drivers. Dr. Snively further indicated that the static (loop) strength of the failed chin straps in these cases was 600 pounds or more. The loadings on the heads and necks of criminals in hangings appear to be similar to the loading by a helmet retention harness in crashes; and a study (Reference 8) has been conducted to determine how much force is applied by the rope in a hanging. This study reveals that a load of approximately 2000 pounds must be applied to the head to insure that the neck is broken. The 2000-pound load can thus be considered the approximate fatal limit for head and neck strength. It thus seems logical to assume that the human neck and chin can sustain a total force of at least 600 pounds without permanent injury.

Current U. S. Navy military specifications MIL-H-19366B and MIL-H-22995 on the APH-5 and APH-6 helmets, respectively, do not specify a load requirement for the chin-strap harness. Both specifications, however, do require a 520-mph wind blast test with the head form tilted backward at 45 degrees. However, this load could not exceed 415 pounds based on the calculation of the drag on a hollow cup at this speed. On the basis of the above discussion, it appears that prevention of helmet removal by tangential impact forces should be provided up to a minimum load of 600 pounds loop strength. A method of testing a helmet to this load is illustrated in Figure 2.

It should be emphasized that the chin strap should pass well <u>under</u> the chin (even if a chin cup is used) so that maximum resistance to rotation of the helmet on the head can be achieved. The chin strap should also cover the maximum practical area to insure minimum pressure; Reference 2 suggested a 1-inch minimum width and a 1/16-inch minimum thickness of the strap.

Aftward forces which act tangential to the helmet surface will rotate the helmet backward to such a point that its lower rim rests against the nape of the neck, and further rotation occurs only by chin-strap elongation and neck deformation. The chin-strap elongation can be reduced easily by proper design and material selection. It is suggested that the strap elongation be limited to 1/2 inch (at 600 pounds), as illustrated in Figure 2. Neck deformation, however, is not so easily prevented. The degree of neck deformation can be reduced by proper helmet geometry;

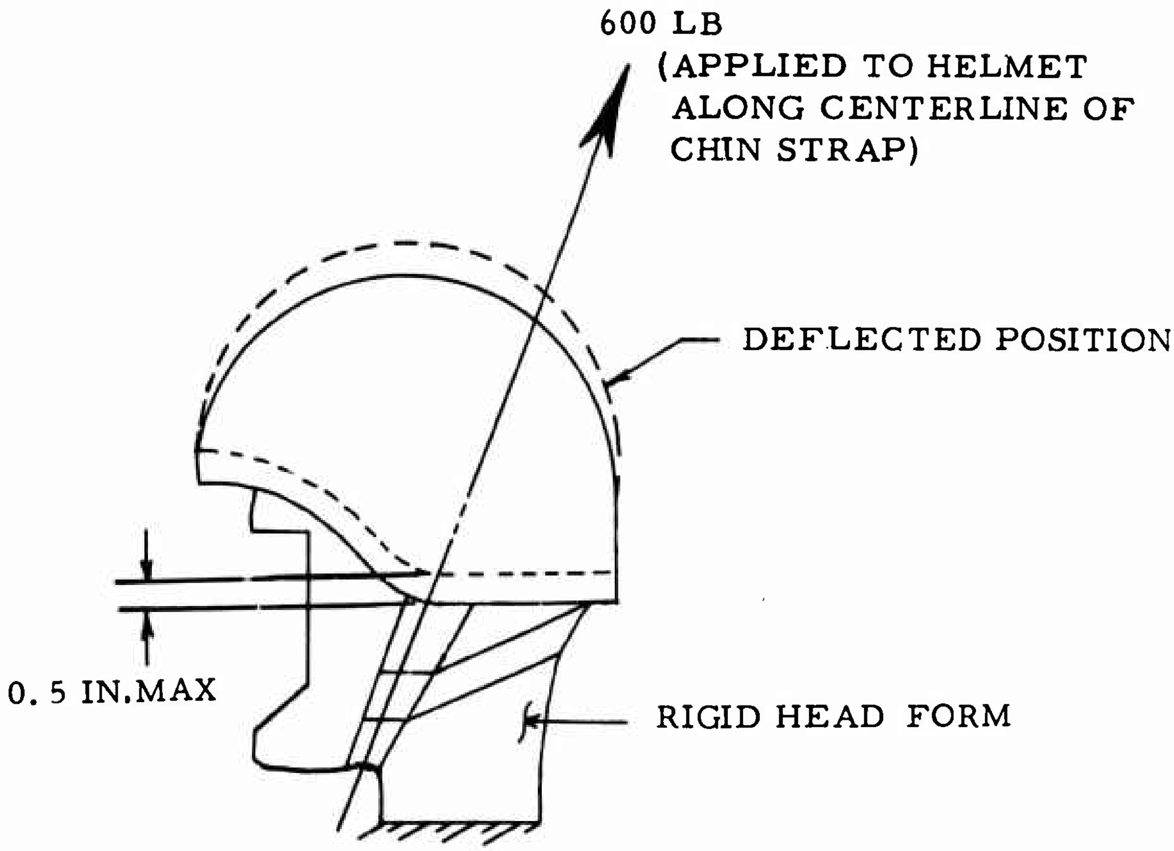


Figure 2. Suggested Chin-Strap Test Method for Strength and Elongation.

that is, the back lower edge of the helmet should be located further down along the neck area than is the practice with current APH-5 helmets. In addition, the helmet back lower edge should be padded with sufficient material to insure minimum pressure in the nape area when backward rotation occurs. It is suggested that this contact area be approximately 4 square inches.

Removal of a helmet by inertia forces alone may occur in accidents. In an effort to discover the mechanism of helmet loss caused only by inertia forces, two types of experimental tests were conducted with APH-5 type helmets in this program. The first tests were conducted with helmets installed on an anthropomorphic dummy subjected to crash deceleration forces on an impact sled. The second tests were conducted with helmets installed on a cadaver, which was also subjected to crash deceleration forces on an impact sled. The use of a cadaver for helmet retention harness tests was based on the idea that the human head would best be simulated in this manner, in lieu of tests with volunteers. These tests were conducted primarily to determine the magnitude of the problem; that is, to determine whether or not the standard APH-5 chin-strap and nape-strap harness would permit helmet removal by decelerative forces alone.

RETENTION HARNESS TESTS ON AN ANTHROPOMORPHIC DUMMY

Test Article Description

The helmet used for these tests was similar to the all-purpose APH-5 helmet in overall configuration. The shell, however, was constructed of nine plies of heavy nylon cloth of about 1/4-inch thickness rather than the fiber glass shell of about 3/32-inch thickness used on the APH-5. The chin strap and nape strap used on the nylon helmet were similar to those on the APH-5. The helmet was a 75-percentile size, and it weighed 3-1/2 pounds including the earphones, pads, visor, and retention straps. It did not contain an oxygen mask or a boom microphone.

This helmet was fitted to an anthropomorphic dummy with approximately a 75-percentile head size. Thin fitting pads were used, but the fit was still tighter than would probably be used by an aviator.

Test Procedure

The helmeted dummy was seated in an experimental aircraft crew seat and was restrained by a standard military lap belt and shoulder harness. The crew seat was installed on a decelerative sled as shown in Figure 3.

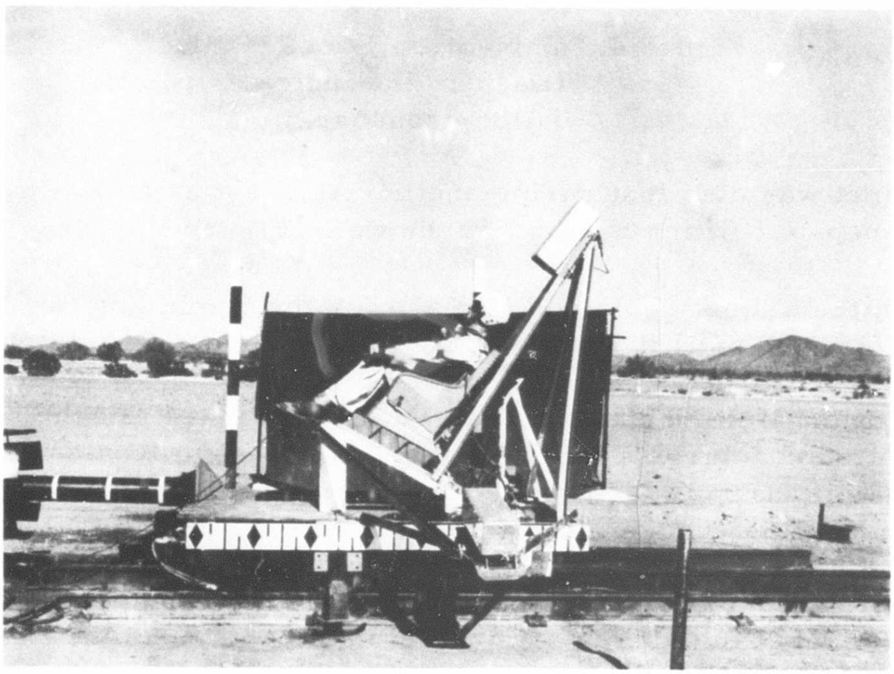


Figure 3. Seating Configuration of Dummy with APH-5 Type Helmet Installed.

The helmet was installed on the dummy during five deceleration tests varying from 22G for 0.20 second in one test to 45G for 0.10 second in the remainder of the tests.

Test Results

The helmet was lost during the 22G test and during one 45G test due to failure of the chin-strap buckle, as shown in Figure 4. The crossbar which attached the other end of the chin strap to the helmet was sheared out of the buckle.

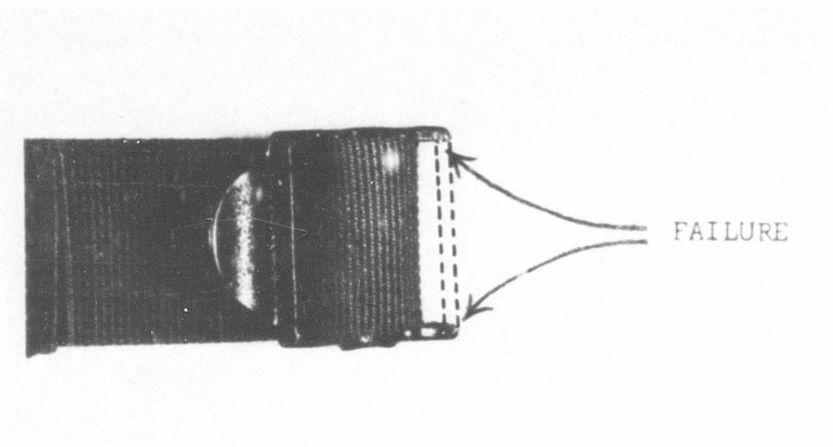


Figure 4. Chin-Strap Buckle Failure. (Dashed line indicates position of failed crossbar.)

The helmet was also lost during another 45G test as a result of a chin-strap "snap-on" fitting failure, as shown in Figure 5.

Although the helmet remained in place for the remaining two tests, it rotated forward until it rested on the dummy's nose in both cases.

In view of the limited number of tests and the tight fit of the helmet, only limited conclusions can be drawn. The tests revealed that the existing chin strap is inadequate to restrain the helmet during a crash in which the floor decelerations reach a level of 22G for a total duration of 0.20 second. Since these deceleration levels could be approached in survivable crashes, it can be concluded that the retention harnesses tested are incapable of restraining helmets subjected to their own inertia forces. One other pertinent point in regard to head protection was revealed in these tests: the head decelerations exceeded the basic floor input decelerations by a factor of 2 to 1. For an input deceleration of 45G, the head reached 90G values for short time spans.

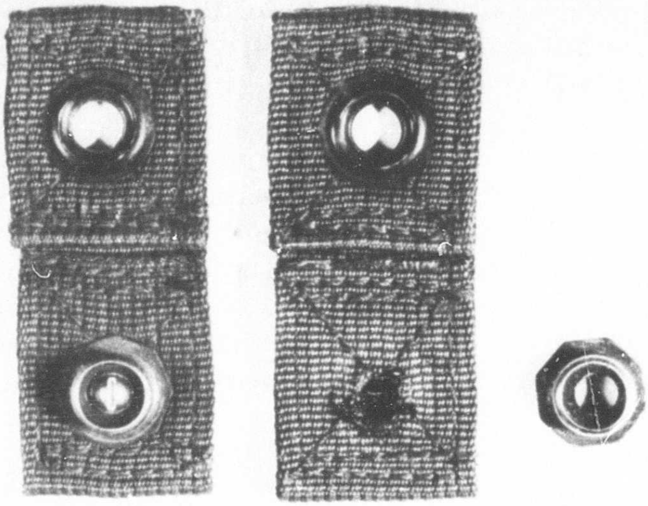


Figure 5. Chin-Strap "Snap-On" Fitting Failure.

RETENTION HARNESS TESTS ON A CADAVER

General

The tests on a cadaver were conducted at Wayne State University, Detroit, Michigan, on 26 and 27 May 1965, through the courtesy of Professor L. M. Patrick and staff of the Wayne State Biomechanics Research Center.

Test Article Description

Two types of helmets, the standard APH-5 military helmet and an experimental helmet (No. X-34) developed under the Reference 2 study, were used in these tests. The pertinent details of the helmets are as follows:

Helmet Identification	APH-5	X-34
Type Suspension	Pads	Sling
Helmet Size (Maximum Percentile)	70	95
Total Helmet Weight*	3.7 lbs	3.8 lbs

*Both helmets were weighted with lead to equal these weights, since this is the average weight of an APH-5 helmet with microphone and oxygen mask.

The helmets were fitted to a 160-pound cadaver whose age at death was between 50 and 60 years. The length of the cadaver's head was 7-7/8 inches, and its width was 6-3/8 inches. These dimensions correspond approximately to a 70-percentile head size.

As can be seen by the percentile dimensions, the APH-5 helmet was very tightly fitted with standard, thin sizing pads, while the X-34 was loosely fitted with 1/2-inch-thick sizing pads between the net sling and the head. For comparison purposes, both helmets should have been of equal size. As stated previously, however, the objective of the tests was to determine the severity of the problem, and it was felt that these helmets could illustrate basic differences between sling and pad suspensions.

Test Procedure

These tests were conducted on the Wayne State University test sled, which achieved a maximum velocity of 40 feet per second and a maximum decelerative load on the cadaver of 40G for approximately 0.03 second. The cadaver was seated upright in a simulated crew seat and was restrained by a conventional lap belt, tiedown strap, and shoulder harness combination.

The instrumentation for the tests included the following items:

1. Seat accelerometer

2. Head accelerometers oriented along the x and z axes (longitudinal and vertical)

3. Shoulder harness load link

4. Lap belt load links

5. One 500-fps Millikan movie camera to record a closeup view of the head and neck during deceleration (positioned at right angle to sled arrestment area)

6. One Fastax 1000-fps movie camera to record a three-quarter view of the tests

7. One 64-fps gun camera to record a three-quarter view of the tests

The tests were conducted at velocity changes of approximately 30, 34, and 37 feet per second. Three tests were conducted at each energy level so that data could be obtained on the cadaver kinematics for (1) the APH-5 helmet, (2) the X-34 helmet, and (3) no helmet. One test was conducted at 40 feet per second with the X-34 helmet only. The neck area of the cadaver was X-rayed after each test.

Test Results

The most significant result of the tests was the fact that neither of the helmets was completely removed from the cadaver's head at decelerative forces of 40G and velocity changes up to 37 feet per second. The APH-5 helmet used in the cadaver tests was equipped with a more ductile buckle than the cast buckle used in the previously described anthropomorphic dummy tests, and the duration of the deceleration pulse was only about one-sixth of that sustained by the anthropomorphic dummy.

The test conditions and some of the recorded data for the last five runs of the test series are shown in Table I. The sled impact velocity, sled peak deceleration, and head decelerations along both axes are recorded.

One point of major interest is that the peak head decelerations exceeded the sled decelerations by a factor greater than 2 to 1. This was also noted in the tests conducted with the anthropomorphic dummy. In view of the age of the cadaver (between 50 and 60 years) and the time span between its demise and its use as a test subject (approximately 6 months), it is realized that muscular resistance would probably be greater with living subjects and that head deceleration levels would probably be lower in actual circumstances. It is doubtful, however, that the 3 to 4G maximum resistance which the neck muscles of a live person could sustain would change the situation for a 40G sled/seat impact.

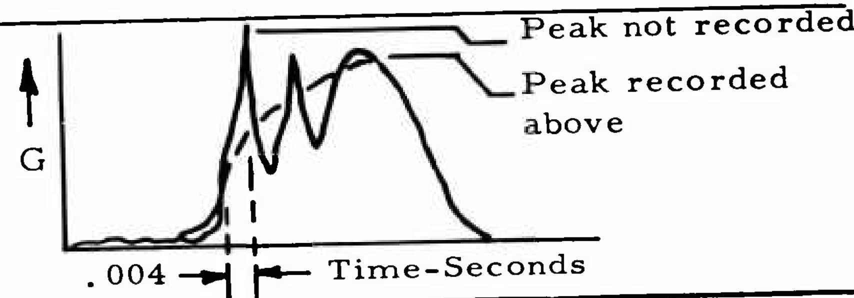
Figure 6 shows the resultant relative velocity of the head with respect to the seat as plotted from the analysis of Run 14. This curve is representative of Runs 14, 15, and 16. It is significant to note that for a seat impact velocity of 37 fps, the cadaver head reached a velocity of about 24 fps with respect to the seat back.

The high-speed film showed that the X-34 retention net shifted approximately 3.5 inches upward on the neck, allowing the helmet to move away from the head, whereas the APH-5 helmet did not move more than half this distance.

TABLE I
HELMET RETENTION TEST RESULTS

Test	Sled Vel. (fps)	Peak Sled Decel.* (G)	Head Decel. X-Axis (G)	Head Decel. Z-Axis (G)	Type Helmet	Comments
14	37	41	75	60	APH-5	Helmet retained.
15	37	41	80	78	X-34 Experimental	Retention harness failed at forward edge on right side over a distance of 3/4 inch. Helmet retained.
16	37	40	90	65	No helmet	—
17	40	46	78	100	X-34 Experimental	Retention harness failure extended further over a distance of 4 inches on right side. Helmet remained in place.
18	35.7	44	56	45	APH-5	No shoulder harness used. Helmet remained in place.

*Peaks with base widths of 0.004 second or less are filtered out.



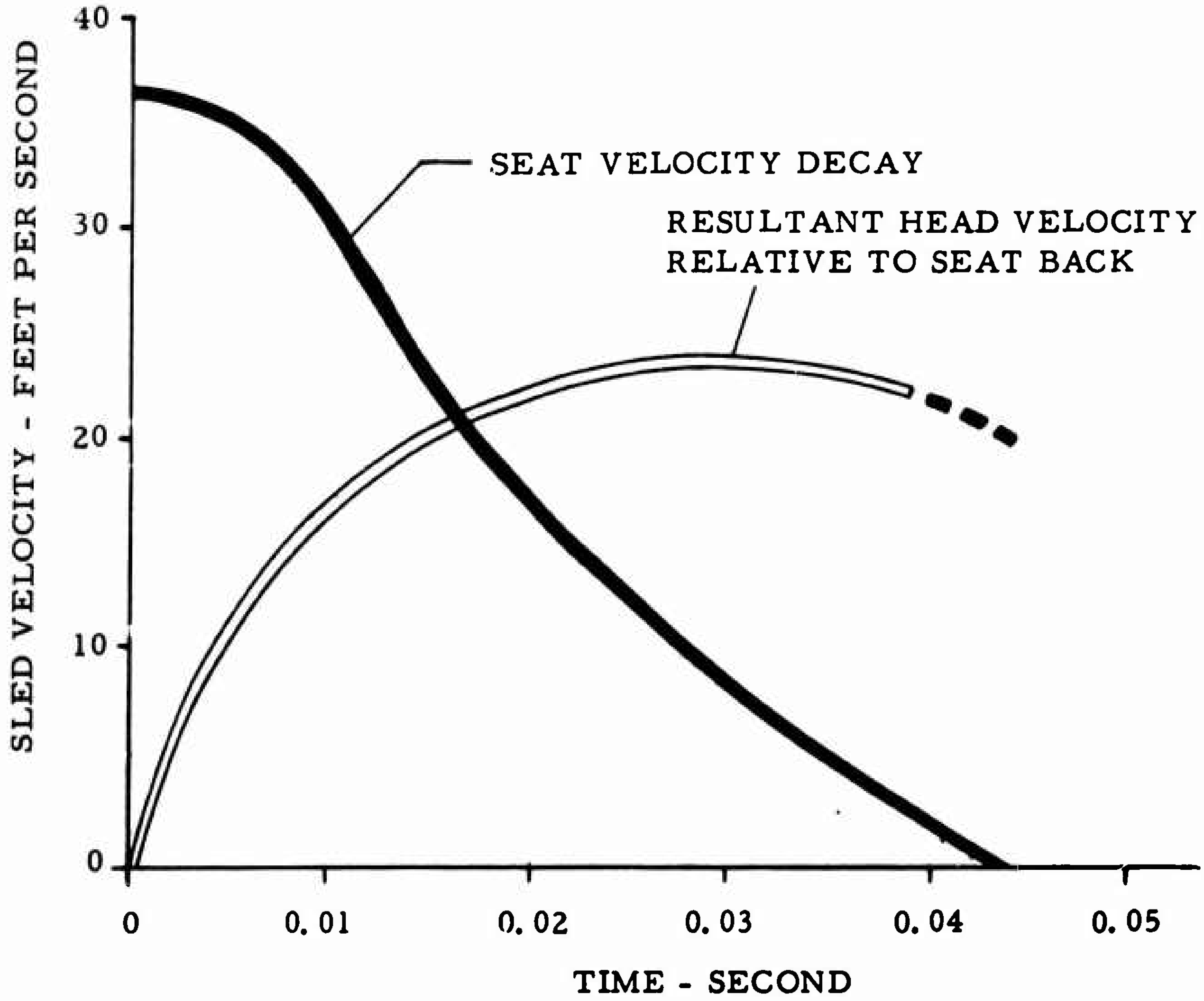


Figure 6. Relative Resultant Velocity of Cadaver Head with Respect to the Seat Back.

It must be realized, however, that the APH-5 helmet was fitted much more tightly than the X-34. If a net-type retention harness is to be used, it should be designed to elongate less than was noted in these tests. The nylon net material used in the X-34 helmet was obviously unsuited for the purpose; this material was originally used in the construction of the X-34 experimental helmet because it was readily available. Dacron net material would be much more suitable because of its lower elongation.

Wayne State University personnel examined the X-ray pictures after completion of the test series and noted that a severe displacement of the spinal column at the fifth cervical vertebra had occurred during the test series. Although it is recognized that such displacement is a serious injury, the conclusion cannot be drawn that the injury was caused by the specific test in which it occurred. Prior exposure of the cadaver to relatively high G levels may have resulted in cumulative damage. Thus,

further tests are needed in order to determine conclusively whether or not a single decelerative pulse at a level of 40G for about 0.10 second will cause irreversible injury whenever a 4-pound helmet is worn.

DISCUSSION

The retention harness tests conducted on the anthropomorphic dummy and the cadaver indicate that it is very difficult to remove a helmet owing to forward rotation caused by helmet inertia forces as long as the chin strap does not break. The tests also showed that the head was decelerated at values more than twice as great as the input deceleration of the seat. Resultant deceleration levels in the cadaver head exceeded 100G for a short time span. The average head weighs approximately 11 pounds, and some helmets add an additional 5 pounds (helmet and auxiliary equipment). This combination can result in a load of 1600 pounds applied to the human head and neck. This 1600-pound load can be compared with the 2000-pound neck breaking strength noted in Reference 8. Can a human being sustain such forces and remain conscious during an impact? Certainly, this is the goal to seek in a helmet design for aviators. Special restraint of the head/helmet mass may be necessary to achieve the goal of consciousness during "survival limit" decelerations. The recent work of Lombard, Stapp, Mosely, and Nelson with guinea pigs, chimpanzees, and humans concludes that head restraint is very beneficial to increased acceleration tolerance (Reference 4). In any event, the high deceleration values noted in these tests indicate a need for minimum helmet weight in order to reduce the loads on the neck muscles under these conditions.

ANALYSIS OF THE PROBLEM

As discussed in Reference 2, a retention harness must encircle the neck closely but comfortably in order to prevent helmet removal. The APH-5 and APH-6 retention harnesses consist of a chin strap and a rather independent nape strap, a combination which does not fit the neck snugly enough, especially when an oversize helmet with a loose nape strap is worn. A helmet retention system requires consideration of the deformation of the retention harness and of the human head and neck structure.

"Limit deformations" of the human neck and head have not been established. Hopefully, the use of cadavers would lead to approximate values. The study would involve:

a. Statistical determination of the chin-parietal dimension A measured under the chin and around the parietal bone and a comparison with neck circumference B as indicated in Figure 7.

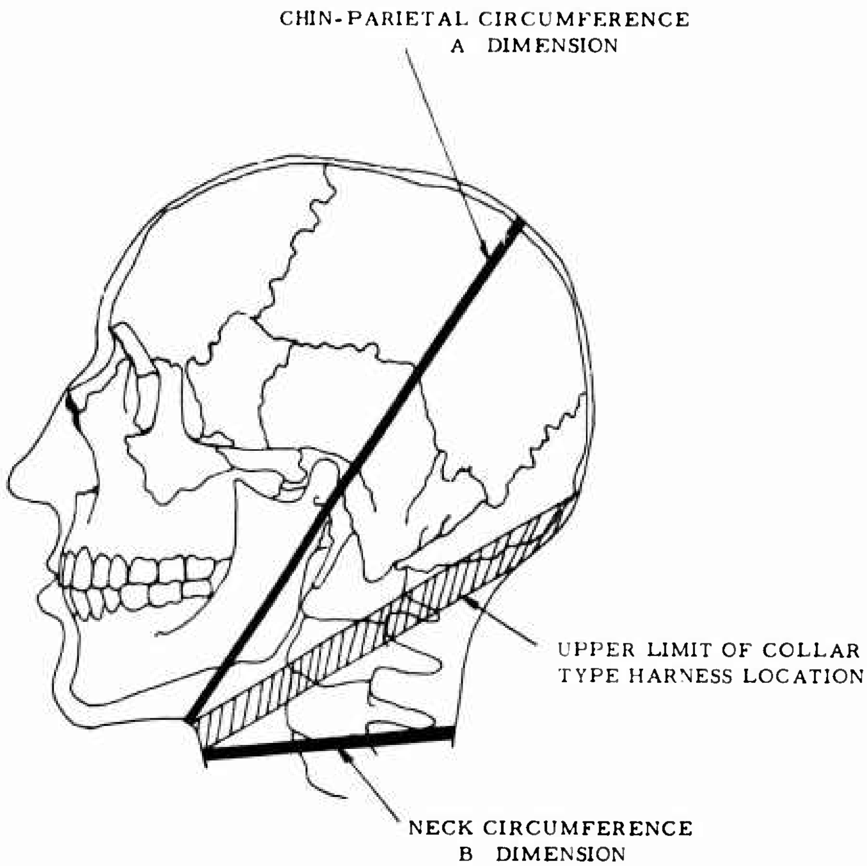


Figure 7. Chin-Parietal Dimension in Relation to Neck Circumference.

b. A suitable test program to determine the amount of decrease in the circumferential dimension indicated in Figure 7; that is, the decrease in this dimension which could be tolerated in a live subject without causing irreversible injury.

c. Fixing the degree of deformation and pressure which can be tolerated in the neck area below the occiput (this information would be needed to determine the tolerance limit of the neck to a loading by the aft lower edge of the helmet).

The determination of the above information was beyond the scope of this program. The retention harness problem was approached in this report with the assumption that the above considerations, while important, could be overlooked, at present, in the interest of expediency if it could be demonstrated that a typical helmet could be restrained on the head of a cadaver or dummy under realistic crash conditions. The tests previously described validated this assumption, since none of the helmets were lost as a result of harness elongation. The losses which occurred owing to chin-strap failure could be easily remedied.

TABLE II
MEASURED HEAD AND NECK DIMENSIONS FROM
A SAMPLE OF 21 MALES
(Average Height = 5' 10.5" - Average Weight - 180 lbs)

	Figure 7	
Sample Unit	A Dimension (In.)	B Dimension (In.)
1	28.7	16.2
2	29.0	17.0
3	27.7	16.2
4	27.7	15.2
5	28.0	15.5
6	27.5	15.0
7	27.5	17.0
8	27.2	16.7
9	27.0	16.7
10	26.5	16.2
11	25.5	15.0
12	29.0	16.7
13	26.5	15.2
14	28.2	15.7
15	26.5	15.5
16	28.2	16.7
17	25.5	13.7
18	26.5	15.2
19	25.5	15.0
20	26.0	14.5
21	27.0	14.7
	Avg. = 27.2	Avg. = 15.7
	Max. = 29.0	Max. = 17.0
	Min. = 25.5	Min. = 13.7

In an effort to determine the range of variation in circumferences A and B as shown in Figure 7, measurements were taken on 21 individuals as shown in Table II. Note that the ratio of the chin-parietal circumference to the neck circumference is on the order of 2 to 1. The average chin-parietal circumference was 27.2 inches, and the average neck circumference was 15.7 inches. Therefore, a retention harness would have to elongate nearly 100 percent in order to permit a properly designed and fitted helmet to become detached owing to inertia forces. It is obvious, however, that the helmet should not be permitted to move to such a point that a large head area becomes exposed regardless of the manner in

which the helmet is dislodged. A review of Figure 7 indicates that the most effective harness "collar" to prevent the vertical movement will be located on a line between the chin/neck intersection to a point just below the occipital bone. The collar will be most effective at this location because the rate of circumference change is greatest at this point.

It was recommended in Reference 2 that the retention harness prevent helmet removal under an inertia loading of 45G times a factor of 2, or 90G. The tests on the dummy and the cadaver corroborate this value, that is, the head decelerations reached 100G, and it seems reasonable to assume that the helmet decelerations were equal to the head decelerations. If a maximum weight of 5 pounds is assumed for a helmet, then the removal force is 5 pounds x 90G = 450 pounds. The helmet should sustain this much load in a test, as illustrated in Figure 8. The test method suggested in Figure 8 is based on the fact that the head pivots forward during longitudinal impacts and comes to rest on the chest. This test simulates the helmet's inertia force. The vertical movement of the helmet on the head form should not exceed 1.5 inches at its aft base, to insure that the area of coverage is not reduced greatly during an impact.

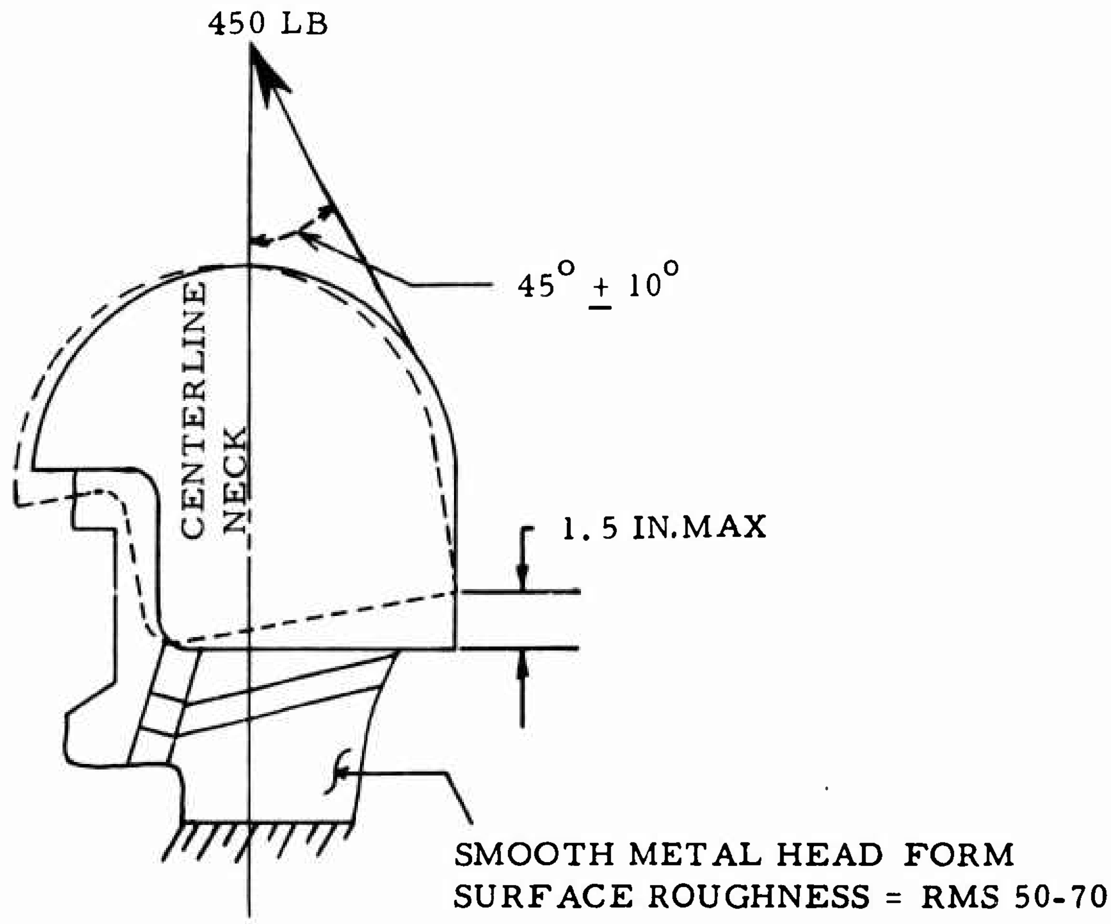


Figure 8. Suggested Retention Harness Test Method for Strength and Elongation.

A collar-type retention harness which can be retrofitted to an APH-5 helmet was constructed by the U. S. Army Natick Laboratories during the course of this study. This harness was sent to the United States Army Board for Aviation Accident Research (USABAAR) for evaluation. Subsequently, USABAAR sent the harness to AvSER for test and evaluation.

The retrofit harness is constructed of a nylon net material with a built-in chin-strap and drawstring adjustment at the rear. The harness was static tested on a metal head form in a manner to simulate removal by inertia forces as previously shown in Figure 8. This harness sustained a load of about 200 pounds before failure; this load is slightly less than half of the 450-pound load recommended in this report. However, if the net were reinforced with a webbing border, it is estimated that the harness would pass the test. Further details on the test procedure and results of the tests on the retrofit harness are included in the Appendix.

IMPACT TEST METHODS

INTRODUCTION

Equally important as the development of design criteria for helmets is the selection of a suitable method of impact testing to insure that the finished product provides proper protection. Although many different testing arrangements are possible, all of the arrangements can be classified under one of the following methods:

Method I   Fixed Head Form and Movable Impacting Mass
Method II   Movable Head Form and Fixed Impacting Mass
Method III   Movable Head Form and Movable Impacting Mass

These test methods have been discussed on a theoretical basis in Reference 2, in which it was shown that any of the methods could be used. However, it was further noted that interpretation of the test results was more difficult with Method III; for example, in Method III, only about 50 percent of the impact energy can be expected to be absorbed by the helmet, and the exact energy absorbed and the rebound characteristics of the helmet are more difficult to determine. If this is understood, then no appreciable problem exists; however, if this fact is not considered in comparing tests with either of the other two methods, then erroneous conclusions could be drawn. Method I offers certain advantages over the other methods with respect to simplicity of the test setup; however, it does not allow a direct measurement of head deceleration, which is currently used as an evaluating parameter for the helmet being tested. Method II permits a direct measurement of head deceleration, but it adds the problem of properly aligning the head center of gravity for varying impact locations. Both Methods I and II allow simple determination of the energy-absorbing capacity of the helmet and thus are considered to be more appropriate for the evaluation and comparison of helmet performance.

In order to compare the results which would be obtained by Methods I and II, the following test program was conducted.

TEST OBJECTIVES

The objectives of the tests were as follows:

1. To determine the significant differences between the deceleration pulses noted for equal energy impacts by test Methods I and II.

2. To determine the effect of foam density on the peak deceleration value obtained by the two test methods.

TEST ARTICLE DESCRIPTION

A cross-sectional sketch of the hemispherical specimens used in these tests is shown in Figure 9. The materials used in the specimens are listed in Table III.

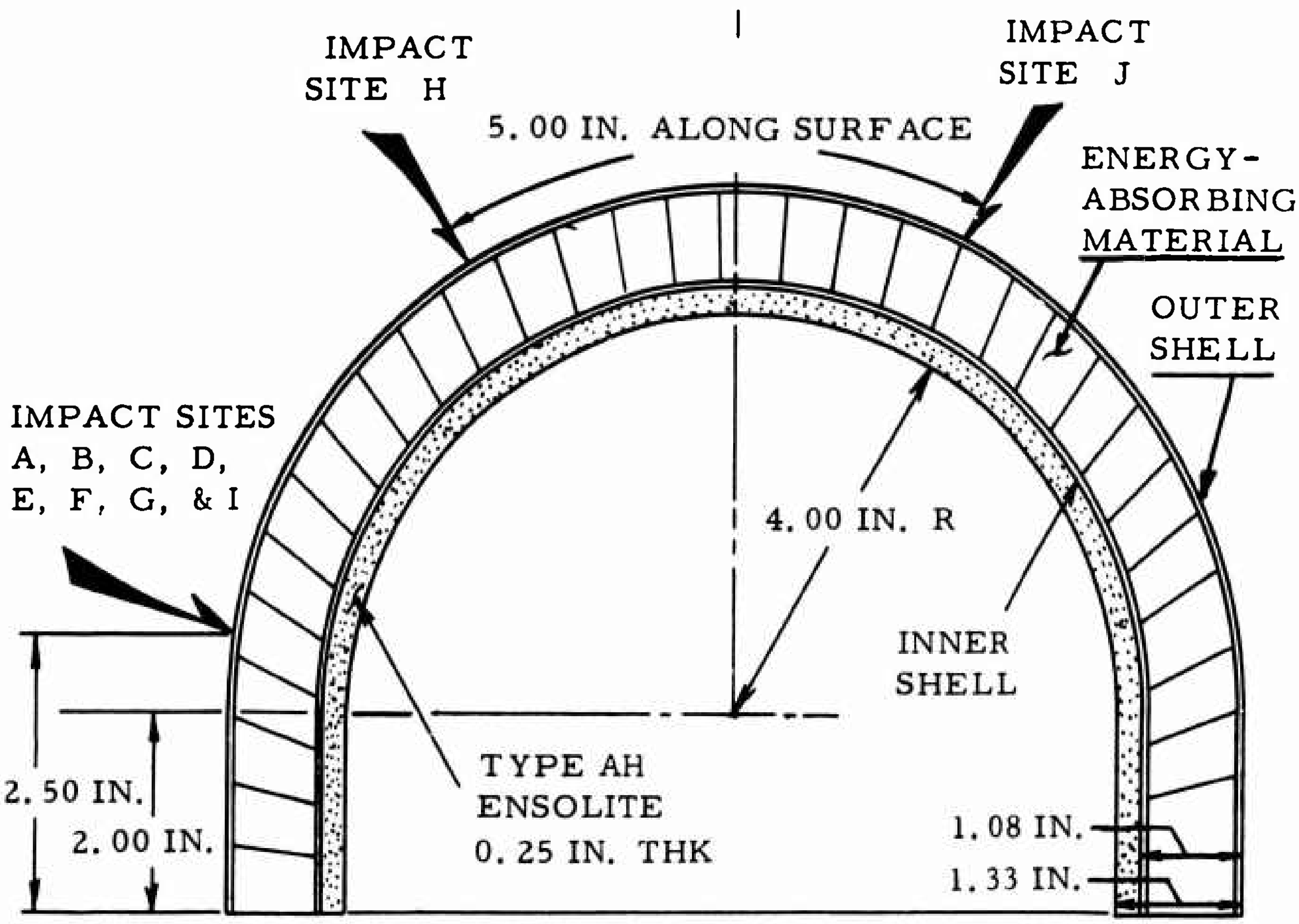


Figure 9. Section of Hemispherical Double-Shell Test Article. (Geometry and Location of Impact Sites)

The annealed 6061 outer shell material was selected because it was readily available and easily formed. It had previously been determined (Reference 2) that a ductile outer shell was desirable; therefore, the shells were annealed after forming.

The expanded polystyrene form was selected because of the consistent mechanical properties obtainable in a 1-inch-thick slab of this material. The densities were checked and found to be within 4 percent of the specifications.

TABLE III
TEST ARTICLE DESCRIPTION

Specimen	Outer Shell Material	Outer Shell Thickness (in.)	Foam*** Liner Thk. (in.)	Foam Density (lb/ft^3)	Inner* Shell Material	Inner Shell Thickness (in.)	Inner** Liner Material	Total Material Thk. (in.)	Total Specimen Wt. (lb)
X-37	6061-0 aluminum (annealed)	0.04	1.0	2.0	3-ply fiber glass 8 oz per sq yd, 22-thread cross weave	0.04	Type "AH" Ensolite (0.25 inch thick)	1.33	1.86
X-38	"	0.04	1.0	2.0	"	0.04	"	1.33	1.95
X-39	"	0.04	1.0	2.0	"	0.04	"	1.33	1.90
X-40	"	0.04	1.0	4.0	"	0.04	"	1.33	2.12
X-41	"	0.04	1.0	4.0	"	0.04	"	1.33	2.18
X-42	"	0.04	0.5	4.0	"	0.04	"	0.83	2.20

* Fiber glass bonded with a 50% ratio of epoxy to hardener.
** Manufactured by U. S. Rubber Company.
*** Expanded polystyrene foam - manufactured by Dow Chemical Co., trade name "Styrafoam".

The outer shell was inlaid with small blocks (3/4 inch square) of 1-inch-thick material. Extreme care was exercised in attaching these blocks to the outer shell to prevent premature crushing of the blocks by handling. The blocks were attached to the outer shell with a thin layer of epoxy cement.

The three layers of fiber glass for the inner shell were soaked in epoxy and laid in place on the blocks. Pressure was then applied by a rubber pressure bag to insure a uniform thickness of the fiber glass/epoxy layer. The final thickness of this layer was approximately 0. 040 inch.

The type AH "Ensolite" inner liner was attached with strips of tape, since the method of attachment was unimportant for these compression type tests. The specimen closely approximated a typical double-shell helmet suitable for U. S. Army aircraft use. Funding of this effort did not permit similar tests on helmets of the single-shell type; and while this should be accomplished, it is tentatively assumed that similar comparative results will be obtained on such helmets by the two test methods.

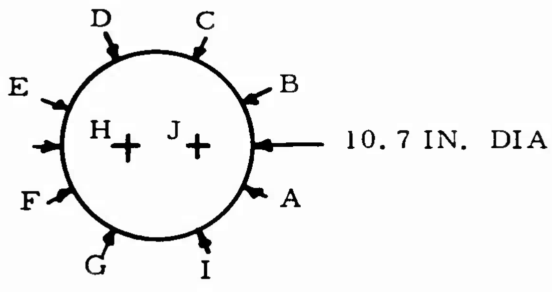
TEST PROCEDURE

The test procedure for the six specimens is outlined in Table IV. The impact sites were selected in the sequence shown so that the crushing of the outer shell and foam in one impact would be far enough removed from the site of the next drop to have a negligible effect on the results.

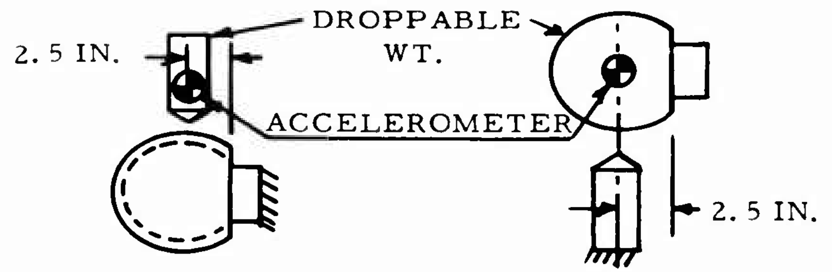
For Method I (impactor drop), a head form, cast of magnesium to a 50-percentile size, was rigidly mounted to a steel jig, which in turn rested on a concrete floor. The hemispherical specimens were installed over this head form and attached loosely with tape to prevent removal upon rebound. The head form was so designed that it could be positioned on the steel jig for lateral and crown impacts. The test setup for a crown impact is shown in Figure 10.

The same head form used for Method I was used for Method II (head form drop). In this case, however, the impact surface was rigidly mounted to the floor and the head form was elevated and dropped. It was necessary to attach a lightweight (1. 0 pound) droppable jig or cage to permit elevation, release, and guidance of the head form onto the impact surface. The test setup for a crown impact onto a flat surface is shown in Figure 11.

TABLE IV
TEST PROCEDURE



IMPACT SITES



IMPACTOR DROP
METHOD I

HELMET/HEAD DROP
METHOD II

TEST METHODS

Test Method		METHOD I				METHOD II				METHOD I			METHOD II		
Impact Surface		90-Degree Corner Surface								Flat Surface					
Impact Site		A	B	C		D	E	F		G	H		I	J	
Specimen	Foam Density (lb/ft^3)	Impact Vel. (ft/sec)			Drop Wt. (lb)	Impact Vel. (ft/sec)			Drop Wt. (lb)	Impact Vel. (ft/sec)		Drop Wt. (lb)	Impact Vel. (ft/sec)		Drop Wt. (lb)
X-37	2.0	10	14	18	13.71	10	14	18	13.84	14	18	13.91	14	18	13.84
X-38	2.0	10	14	18		10	14	18	13.93	14	18		14	18	13.93
X-39	2.0	10	14	18		10	14	18	13.88	14	18		14	18	13.88
X-40	4.0	10	14	18		10	14	18	14.10	14	20		14	20	14.10
X-41	4.0	10	14	18		10	14	18	14.16	14	20		14	20	14.16
X-42*	4.0	10	12	14	13.71	10	12	14	14.18	12	14	13.91	12	14	14.18

*Specimen liner is only 1/2 inch thick.

Item Identity

1. Guide Rods
2. Release Mechanism
3. Droppable Impactor (13.8 lbs)
4. Accelerometer Cable
5. Hemispherical Specimen
6. Magnesium Head Form
7. Steel Support Jig
8. Breaker To Actuate Camera Shutter

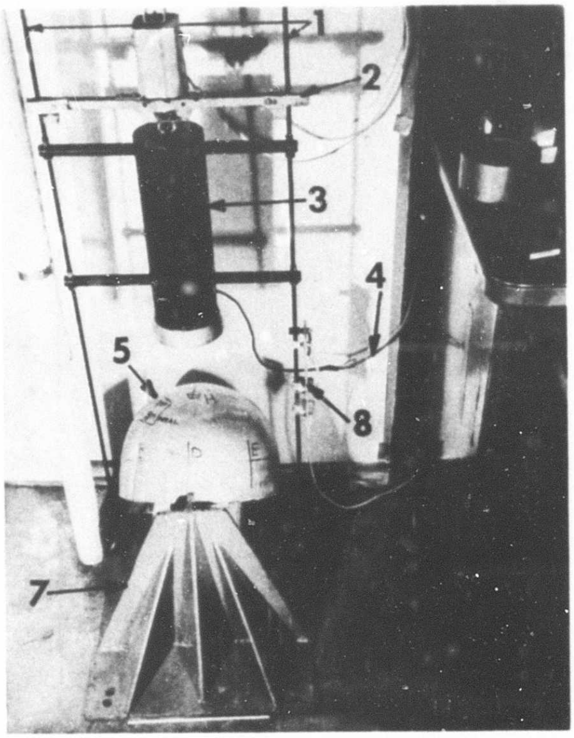


Figure 10. Test Setup for Method I (Impactor Drop with **Flat Surface**).

Item Identity

1. Guide Rods
2. Release Mechanism
3. Droppable Cage (1 lb)
4. Droppable Magnesium Head Form (10 lbs)
5. Droppable Hemispherical Specimen (2 lbs)
6. Accelerometer Cable
7. Impact Surface
8. Breaker To Actuate Camera Shutter

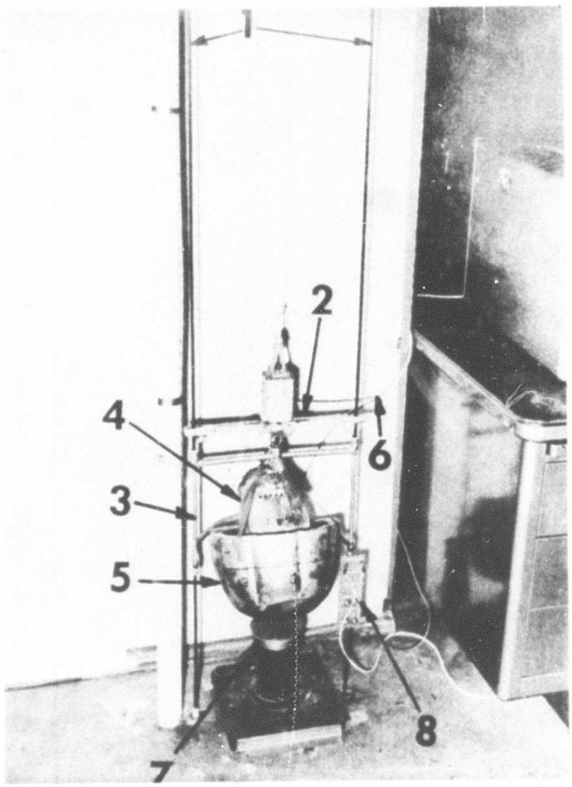


Figure 11. Test Setup for Method II (Head Form Drop).

Two types of impact surfaces were used: (1) flat surface and (2) 90-degree corner with a 0.12-inch radius at the edge. It was felt that these two surfaces would illustrate any major differences caused by this variable. A study in Reference 2 indicated that these two surfaces were prevalent in the cockpits of most U. S. Army aircraft.

The deceleration pulse was recorded in both test methods by an accelerometer mounted rigidly inside the impactor and head form. The specifications of this accelerometer are as follows:

Manufacturer/Model	Statham A69TC-500-350
Design Acceleration	± 500G
Frequency Response	2500 cycles per second
Natural Frequency	3800 cycles per second
Weight	3 ounces

The deceleration-time data for each drop test were recorded from an oscilloscope by a Polaroid camera. Details of the test setup are shown in Figure 12.

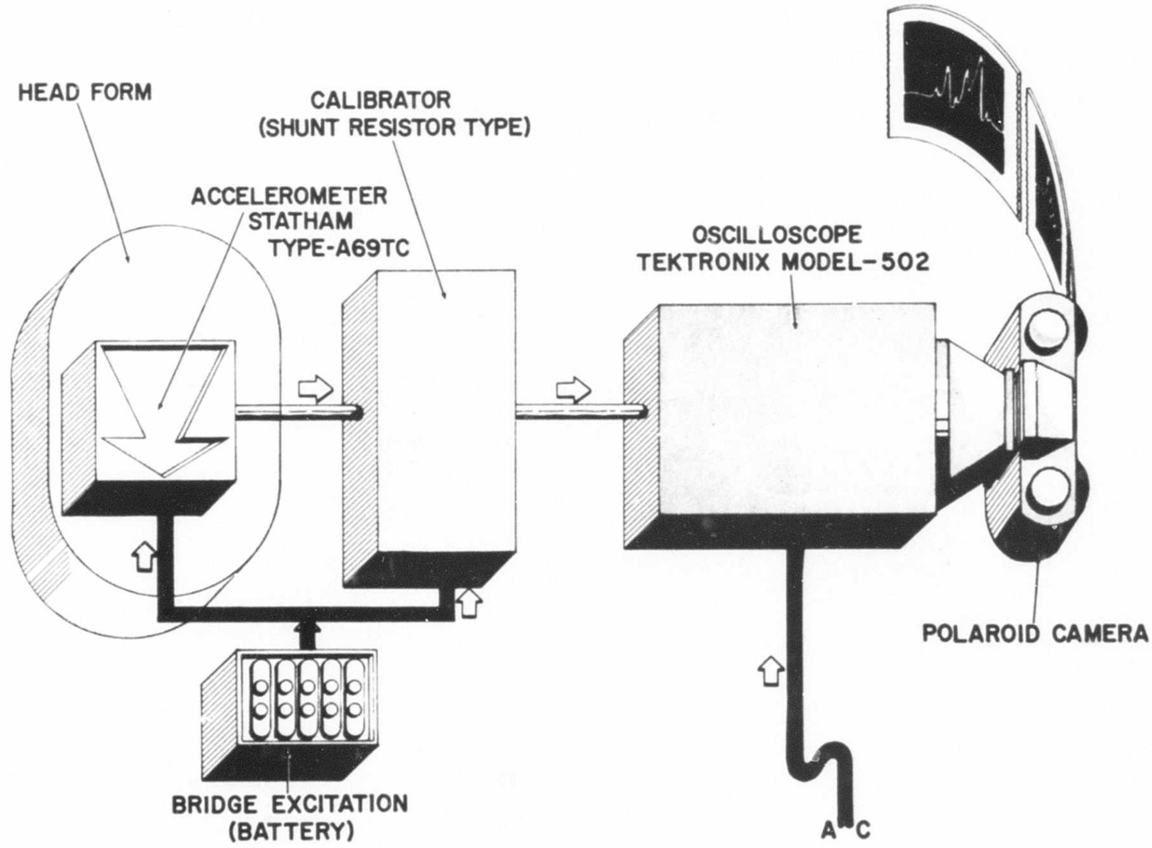
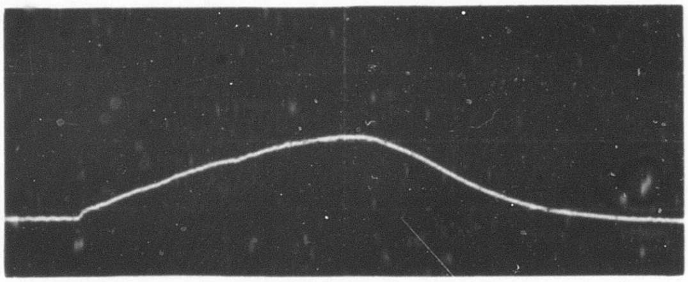


Figure 12. Instrumentation Test Setup.

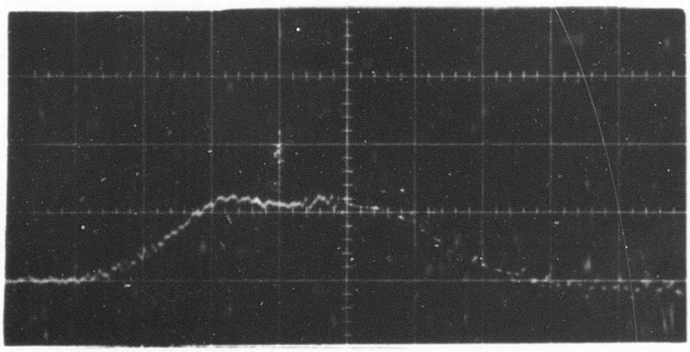
TEST RESULTS AND DISCUSSION

Sixty drop tests were instrumented and recorded; six specimens were impacted at ten different locations on each specimen. This number of tests permitted at least two identical drops for all the test conditions so that the accuracy of each test point could be checked.

Samples of the recorded deceleration-time data from the oscilloscope camera are shown in Figures 13 and 14. Figure 13 presents the data from a 90-degree-corner surface impact at 14 feet per second, while Figure 14 presents the data from a flat surface impact at 18 feet per second. The samples shown contained a foam density of 2.0 pounds per cubic foot. The 4.0-pound foam yielded similar traces with the exception that the deceleration values were higher and the time durations were smaller. The traces reveal that the hollow metal head form (Method II) induced high-frequency oscillatory pulses, whereas the solid metal



METHOD I (IMPACTOR DROP)

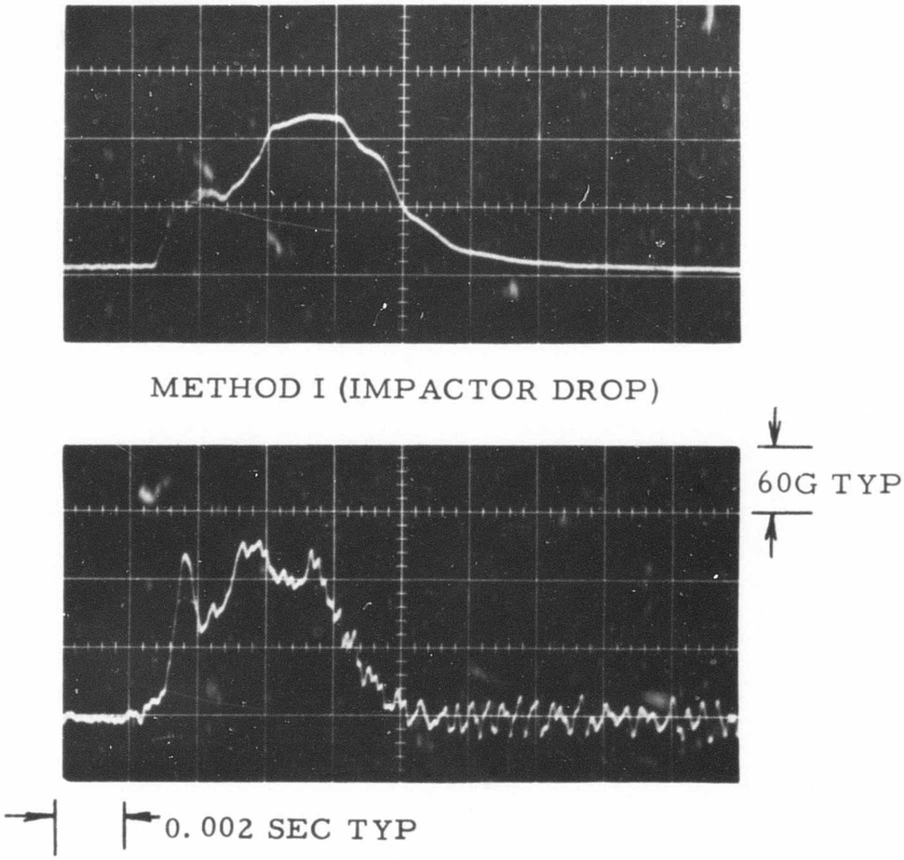


60G TYP

0.002 SEC TYP

METHOD II (HEAD FORM DROP)

Figure 13. Typical Deceleration-Time Trace for 14-Feet-Per-Second Impact onto a 90-Degree-Corner Surface. (2.0-pound Foam Density)



METHOD I (IMPACTOR DROP)

METHOD II (HEAD FORM DROP)

Figure 14. Typical Deceleration-Time Trace for 18-Feet-Per-Second Impact onto a Flat Surface. (2.0-pound Foam Density)

impactor did not. It is probable that the use of a solid head form with the correct density would reduce the high-frequency components. A hard wood or plastic head form is recommended in lieu of a hollow metal head form as was used in these tests.

The instrumentation used was identical for test Methods I and II. However, it was necessary to interpolate between the "peaks" and "valleys" of the Method II data in order to make a true comparison with the Method I data, which did not contain the high-frequency pulses.

The traces were analyzed and the peak accelerations recorded as shown in Figures 15, 16, 17, and 18. The data in these figures are self explanatory; however, several significant trends are worth noting. For example, the Method I (impactor drop) in Figure 15 reveals that the 2.0-pound

foam material is obviously inadequate to sustain impacts at a velocity of 18 fps. The "knee" shown in the curve at approximately 16 fps was not accurately determined but emphasizes the obvious rapid change in the peak G value slope with velocity change. Most important is the fact that the energy-absorbing material is fully compressed at an impact velocity of 18 fps, and this bottoming of the energy-absorbing material results in rapidly increasing deceleration values. Wide scatter appears in the data when bottoming occurs, that is, the G value varies between 144G and 283G, whereas the deceleration data at 14 fps were very consistent in that all three drops read exactly 71G. Examination of the upper curve with the 4.0-pound foam density indicates that no bottoming is occurring at 18 fps and that the acceleration levels of 128G and 136G are within the range of scatter to be expected.

Examination of the 1/2-inch-thick, 4.0-pound foam curve in Figure 15 reveals that bottoming is beginning at about 14 fps. The G values recorded for the 1/2-inch-thick foam are slightly higher than those recorded for the 1-inch-thick foam at equal impact velocities. This is to be expected, since for a given input energy the 1/2-inch foam is carried to a higher strain and hence to a higher stress.

Figure 16 shows the peak G values recorded for test Method II (head form drop). The same trends are evident as for test Method I, although slightly more scatter occurs in the data points. The method of "least squares" was used in determining the curves shown.

Figure 17 shows the same information as was plotted in Figure 15 with the exception that a flat impact surface was used in these tests. These curves show that the 4.0-pound foam results in excessive deceleration values (125G+) at rather low impact velocities. In general, the G values for the 4.0-pound foam are about 50 percent greater than those for the 2.0-pound foam. This percentage increase would, no doubt, be greater if a thinner outer shell were used, since a larger portion of the crushing strength would be contained in the foam liner rather than in the outer shell.

Figure 18 shows the flat impact surface data for test Method II. It can be seen that the data follow the same pattern as with Method I with the exception that the deceleration values are higher.

The deceleration data are superimposed in Figure 19; that is, the two test methods and both types of impact surfaces are shown in the same figure. The maximum differences between the peak deceleration levels are shown. The term "maximum difference" is used to denote the fact

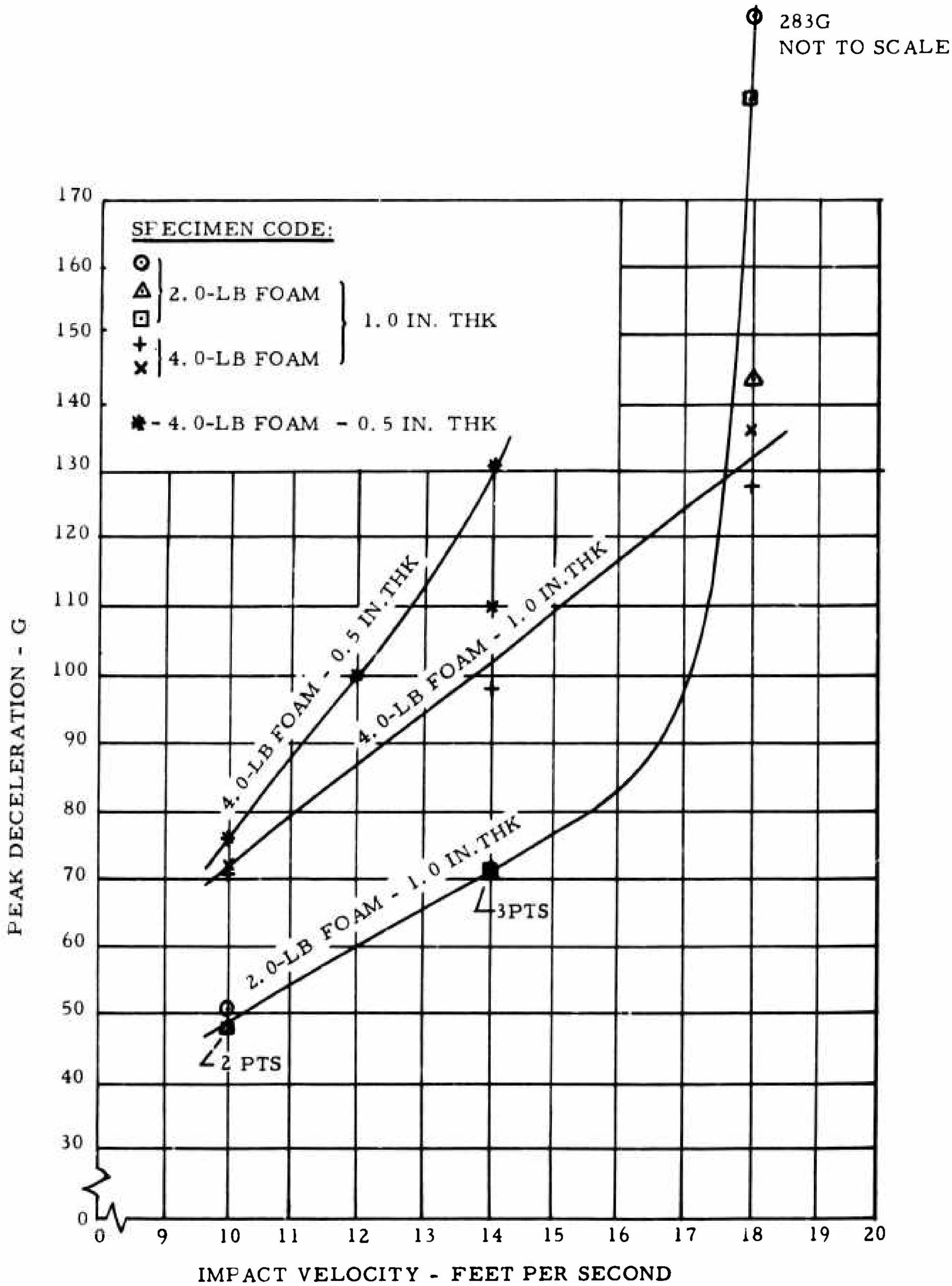


Figure 15. Peak Recorded Decelerations at Varying Impact Velocities for Test Method I - 90-Degree-Corner Impact Surface.

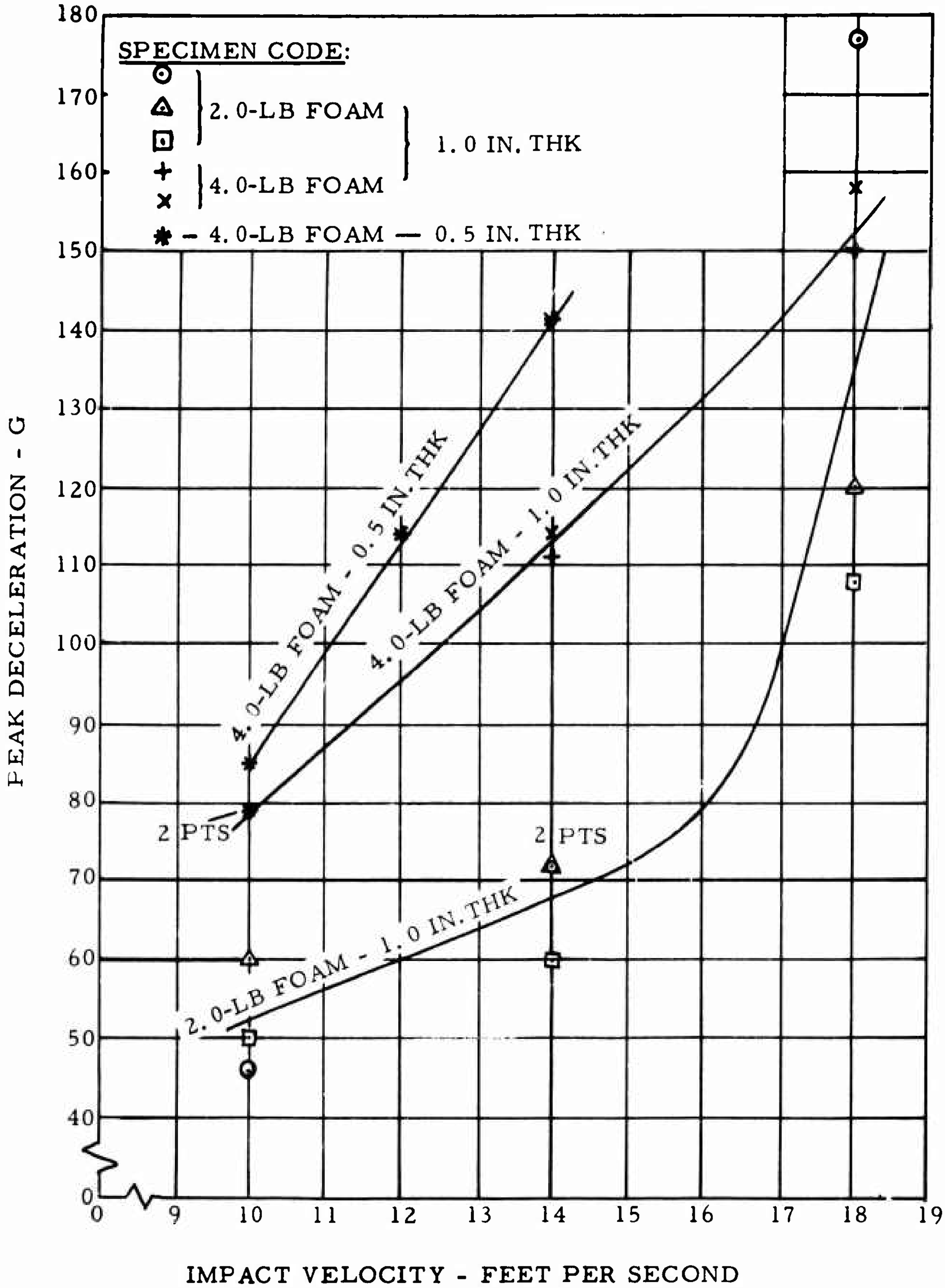


Figure 16. Peak Recorded Decelerations at Varying Impact Velocities for Test Method II - 90-Degree-Corner Impact Surface.

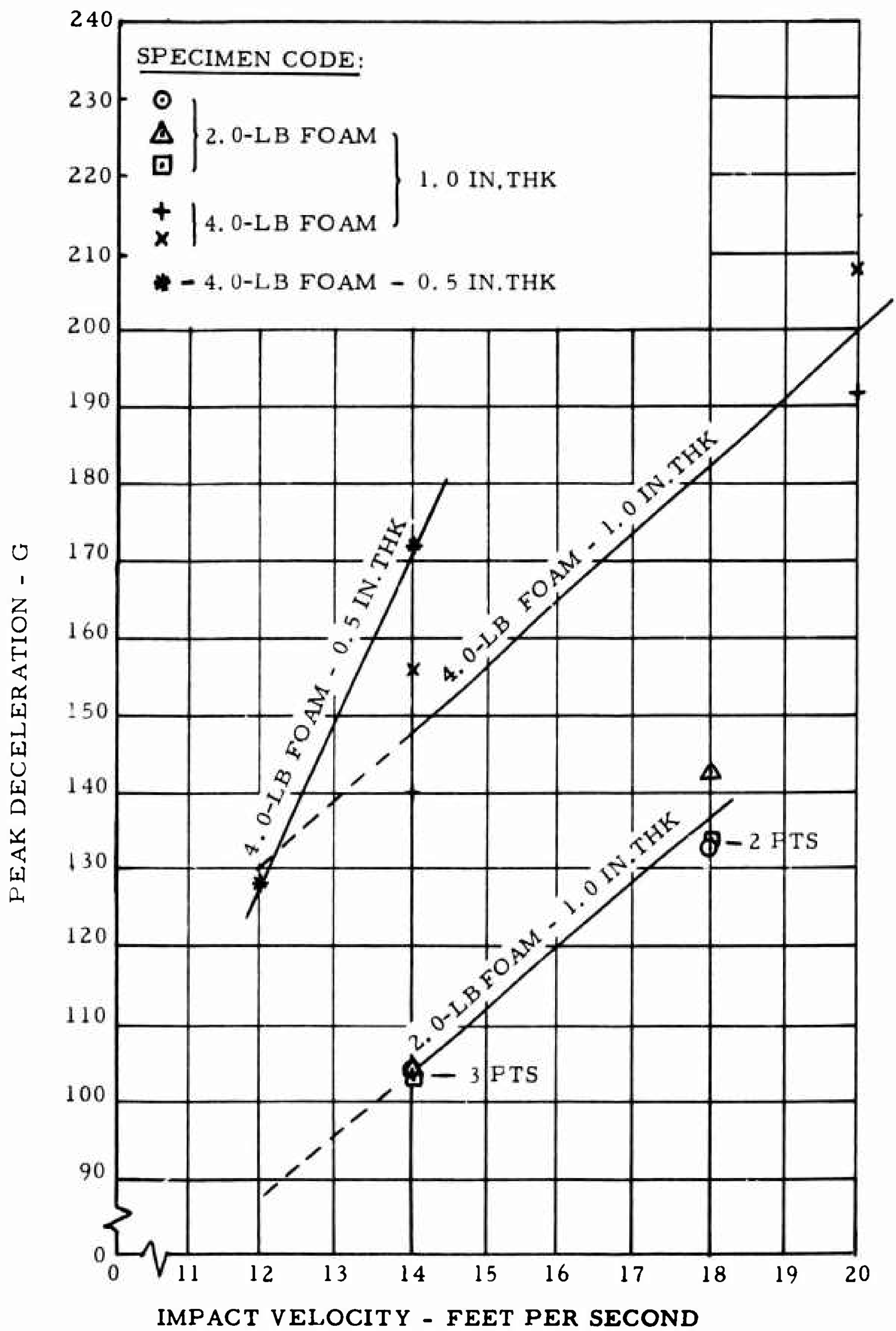


Figure 17. Peak Recorded Decelerations at Varying Impact Velocities for Test Method I - Flat Impact Surface.

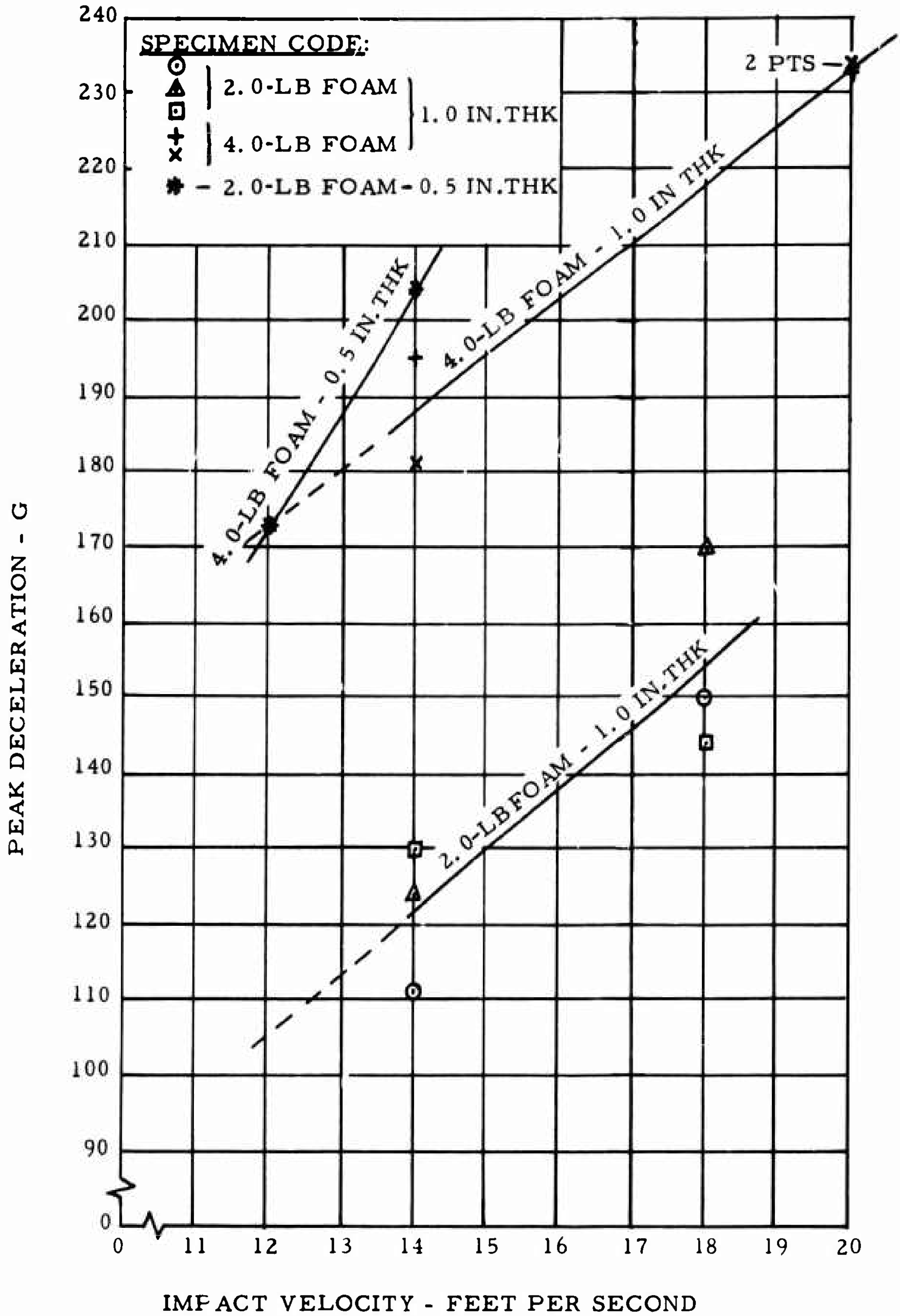


Figure 18. Peak Recorded Decelerations at Varying Impact Velocities for Test Method II - Flat Impact Surface.

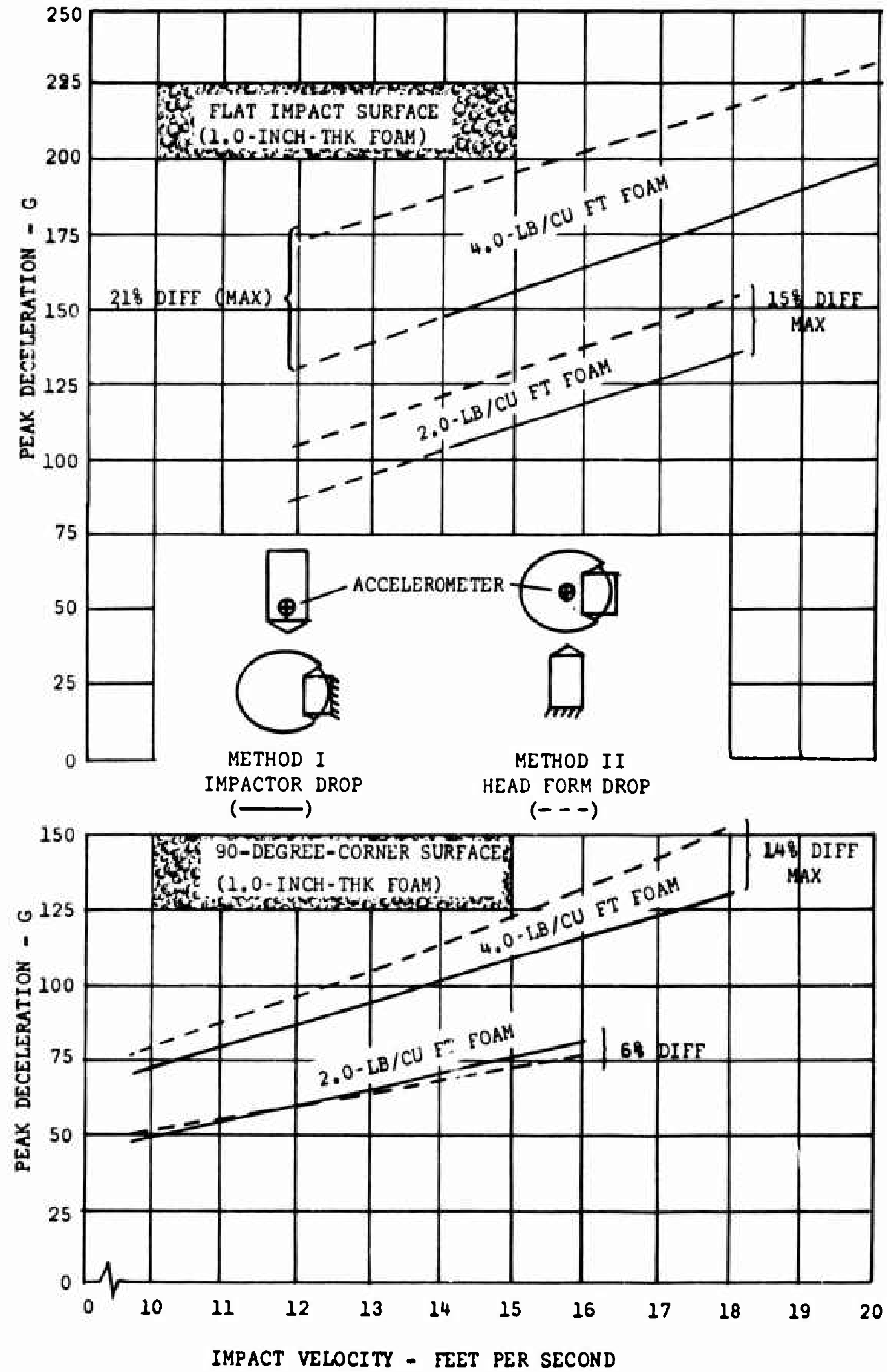


Figure 19. Peak Deceleration Difference as a Function of Impact Velocity and Foam Density.

that the percentage of difference for the deceleration levels varies somewhat with the impact velocity and that the values selected are maximum. The highest deceleration difference shown is 21 percent for the 4.0-pound foam material. This is not considered significant, however, since the 4.0-pound foam material is not expected to be used because it resulted in values in excess of 150G for both test methods. The 2.0-pound foam material with a corner surface shows a negligible difference. Thus, the 15-percent value shown for the flat impact with the 2.0-pound foam is considered to be the significant differential factor.

The theoretical analysis shown in Reference 2 indicated that the Method I (impactor drop) test could yield deceleration values about 7 percent higher than Method II (head form drop); however, with a different selection of the constants in the equation, the percentage of difference could vary from 10 percent higher for the head form drop to 20 percent lower. Further analysis of the Reference 2 equation also indicates that no allowance was made for any relative movement between the helmet specimen and the head form. In actual practice, some movement (up to about 1/8 inch) does occur during the compression of the 1/4-inch-thick inner liner; this movement appears to result in an initial "dynamic overshoot" at the higher impact velocities with a flat impact surface, as can be seen in Figure 14. The tendency is more pronounced with Method II (head form drop), as would be expected, since the mass of the head form and drop cage (12 pounds) is about 80 percent of the mass of the impactor (13.8 pounds average) and the "overshoot" should be more on the lesser mass.

Regardless of the true kinetics of the helmet and head form reaction on each other, the actual recorded difference in G levels of approximately 15 percent for the flat surface impacts corresponds closely with the percentage of difference in weight of the impactor and the head form as shown:

$$\frac{\text{Impactor Weight - Head Form Weight}}{\text{Head Form Weight}} = \frac{\text{13.8 lb avg. - 12 lb}}{\text{12 lb}}$$

$= 0.15$, or 15 percent

This close correlation points to the conclusion that the impactor weight should probably be reduced to that of the head form in order to achieve equal G values for equal energy impacts with the flat impactor. Reduction of the impactor weight would result in higher G levels for the corner surface impacts. This would not be a problem, however, since the G values for sharp surface impactors will always be less than those for flat impactors because more material is crushed during a flat impact. That is, a 15-percent increase in the G values for the corner surface would still not exceed the flat surface G levels for equal impact energy. Thus,

it is concluded that the impactor weight should be more nearly equal to the head form weight in order to match the G level of the head form for the critical flat impact.

IMPACT VELOCITIES AND IMPACT SURFACES

This item was discussed in Reference 5; however, a limiting head impact velocity value for design purposes was not specified. The retention harness tests on a cadaver in this report indicated that a relative velocity of about 24 feet per second with respect to the seat back was possible (41G with change in velocity = 37 feet per second). It is probable that this value would be different for a live human because of muscular resistance to relative neck and head movement; however, it would seem reasonable to consider a velocity value of 20 feet per second for a body restrained by a snugly fitted lap belt and shoulder harness. It is recognized that head impact velocities could be much higher for crew members not using a shoulder harness or for those accidents in which the body restraint system fails and the entire torso rockets into surrounding structure; however, these eventualities are considered beyond the scope of protection which can reasonably be provided by a helmet.

The impact site study of Reference 2 indicated that about two-thirds of all fractures occurred in the facial area or in the frontal bone, while the remaining fractures were shared about equally by the parietal, temporal, and occipital bones of the cranium. This percentage indicates that the frontal region should receive the greatest protection on the basis of previous exposure. Also, since the majority of aircraft accidents result in a major impact force in the longitudinal direction, the highest head impact velocities will occur in the same direction. Upon this basis, the following ratio of energy-absorption capacity for each area of the helmet is suggested:

Frontal	-	100 percent
Lateral	-	67 percent
Occipital	-	50 percent
Crown	-	50 percent

This breakdown appears to be reasonable in view of the fact that a reduction in helmet thickness will result in a desirable weight reduction while still providing protection to a reasonable degree. It is noted that the lateral impact receives 67 percent of the energy input to the frontal area; more weight was given to this area than to the crown and occipital areas because of the large number of lateral impacts which occur with helicopters.

It was recommended in Reference 2 that three types of impact surfaces, (1) flat, (2) corner, and (3) cone, be considered for helmet impact tests. The flat surface would yield maximum deceleration values for a given amount of crushing depth, while the corner surface would indicate the ability of the outer shell to serve as a "load spreader" to insure that a maximum area of foam was crushed for such an impact. Finally, the cone surface was to indicate the puncture resistance of the helmet to very sharp, jagged structure which could be seen in a cockpit structure which had been pushed inward during an impact. Further consideration of these impact surfaces indicates that the corner surface test might not be necessary, because the flat surface yields information on the peak deceleration values and the cone surface can yield data on the puncture resistance of the material. Furthermore, the "load spreader" capacity of the outer shell can also be indicated by the cone test; that is, the outer shell must be rigid enough to "spread" the load from the cone. The cone tests conducted in Reference 2 on various types of outer shells indicated that when the shell was too thin or elastic, resistance to penetration was very poor. Thus, it is concluded that the flat and cone surface impacts are adequate to insure proper impact tests of helmets.

The best helmet specimens tested in Reference 2 indicated that the cone impact energy should be about 40 percent of the flat impact energy to prevent penetration of the inner shell. A percentage greater than this does not seem reasonable in view of the remote possibility of such an impact, and this value is recommended for impact tests.

After selection of the maximum impact velocity and the types of impact surfaces, the test conditions can be stated. For an impact velocity of 20 feet per second, the drop height, h, required is

$$h = \frac{V^2}{2\,g}$$

$$h = \frac{20^2}{2(32.2)} = 6.22 \text{ feet}$$

where

h = drop height in feet

V = impact velocity

g - $32.2\ \text{ft/sec}^2$.

It is suggested that this value be reduced to an even 6.0 feet for simplicity of test measurements. The drop heights for the four areas of the helmet with the flat surface and the cone surface can now be stated.

	Impactor Drop Height, Flat Surface	Impactor Drop Height, Cone Surface
Frontal Area	6.0 feet	2.4 feet
Lateral Area	4.0 feet	1.6 feet
Crown Area	3.0 feet	1.2 feet
Occipital Area	3.0 feet	1.2 feet

The flat impactor should be 5.0 inches in diameter as a minimum dimension. The apex angle of the cone should be 90 degrees, and it should contain a 0.06-inch radius. The weight of the impactor should be 11.0 ± 0.10 pounds to simulate the weight of a 50-percentile head in accordance with Reference 7.

The above test conditions should not result in excessive G values. The G levels which could result in unconsciousness were discussed in Reference 2, in which it was noted that G levels are related to the pulse duration. It was recommended that decelerations not exceed 160G for thin helmets and that these values be less for thicker helmets. On this basis, it is recommended that the maximum G level not exceed 180 under any circumstances and that G levels above 150G not exceed a time duration of 2 milliseconds.

The above-stated test requirements can be achieved with a foam liner of a 1-inch thickness in the frontal area along with liner materials similar to those used for the test article in this study. The thickness of crushable material in the crown, lateral, and occipital areas of the helmet could be reduced in accordance with the lower amount of energy to be absorbed in these areas. It is also feasible to construct such a helmet of 50-percentile size which includes a communication system for about a 1.5-pound total weight.

CONCLUSIONS

RETENTION HARNESS ANALYSIS

It is concluded that:

1. The effect of inertia forces on the unrestrained head at high G levels is not well understood, and further research is needed to determine the effect of helmet weight on the tolerance of the neck.

2. The chin-strap strength should be sufficient to retain the helmet on the head under forces of at least 600 pounds as described in this study.

3. The retention harness should insure retention of the helmet under loads of at least 450 pounds as described in this study.

4. Human head decelerative forces can exceed the decelerative force input to the entire body by a factor of 2 to 1.

IMPACT TEST METHODS

It is concluded that:

1. The impactor drop test (Method I) yields consistent test data on the double-shell specimens as tested in this study, and it is easier to instrument than the head form test (Method II).

2. Helmets can provide crash protection at a head impact velocity of about 20 feet per second when striking a rigid, flat surface.

3. The 2.0-pound-per-cubic-foot foam yields tolerable deceleration values. Foams of greater density should be used in helmet construction only after careful evaluation.

RECOMMENDATIONS

RETENTION HARNESS ANALYSIS

Owing to the absence of detailed medical data on the human tolerance to forces in the neck and head area, it is difficult to define the optimum retention harness design and testing procedures. Nonetheless, the severity of the helmet retention problem is such that changes in helmet design should be made now on the basis of the existing information. Thus, it is recommended that:

1. Protection against helmet removal by external, tangential impacts be provided by the use of a chin strap with a minimum elongation of 1/2 inch and a minimum strength of 600 pounds. The chin strap as installed on a helmet should be static tested as shown in Figure 2.

2. Protection against removal of a helmet by inertia forces from the helmet's own weight in an impact be provided for by the use of a collar type retention harness which encircles the neck area snugly. This type of harness is needed to prevent removal of a helmet by forward or lateral rotation. The helmet should be tested as illustrated in Figure 8 to prevent its removal by inertia forces.

IMPACT TEST METHODS

It is recommended that:

1. The impactor drop method be used in the testing of double-shell helmets because of the simplicity and the consistency of the data obtained.

2. A flat surface and a cone surface be used in impact tests as described in this report.

3. Further comparative tests using the impactor drop method and the head form drop method be conducted for results with single-shell helmets if this type of construction continues to be used.

GENERAL

It is recommended that:

1. Further research be conducted on the deceleration limits of the unrestrained head in a forward direction, with consideration given to the effect of increased helmet weight. Such results would be

obtained by deceleration of the entire torso as normally restrained by a lap belt and shoulder harness.

2. The development of a prototype helmet to meet the requirements specified in this report be initiated.

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APPENDIX

STATIC RETENTION TEST OF APH-5 HELMET RETROFIT HARNESS

GENERAL

A helmet can rotate forward and be removed unless some type of harness is used to "anchor" it under the nape of the neck. The proposed retrofit harness attempts to provide a "collar" around the neck when it is fitted properly. Thus, removal of the helmet is prevented unless the harness stretches enough to slide over the top of the head. This test was conducted to determine how much force would be required to stretch the harness and remove the helmet from the head.

TEST SPECIMEN DESCRIPTION

The retrofit harnesses were installed in a medium size helmet, similar to the APH-5 type, made up of nine plies of nylon cloth. The harness was installed in the helmet at the normal attachment points for the chin strap and nape strap. Medium sizing pads were installed in the helmet so that a snug fit could be obtained on a medium size head form. The head form used was a magnesium casting with a paint d surface. The head form surface finish was similar to the finished side of a leather belt. The cast head form contained tapped holes in the neck area which could be used to attach it to a test jig.

TEST PROCEDURE

The magnesium head form was attached to a steel jig as shown in Figure 20. The helmet and retention harness were fitted snugly to the head form.

Thin aluminum straps were attached to the lower back area of the helmet so that a loading jack could be attached. The movement of the helmet was measured by recording the rotation of the lower back edge of the helmet along the surface of the head as shown in Figure 21. The load was recorded by a calibrated strain gage link. One retention harness was tested to failure for a loading parallel to the crown of the helmet, and the other retention harness was tested to failure for a loading of 45 degrees upward and forward.

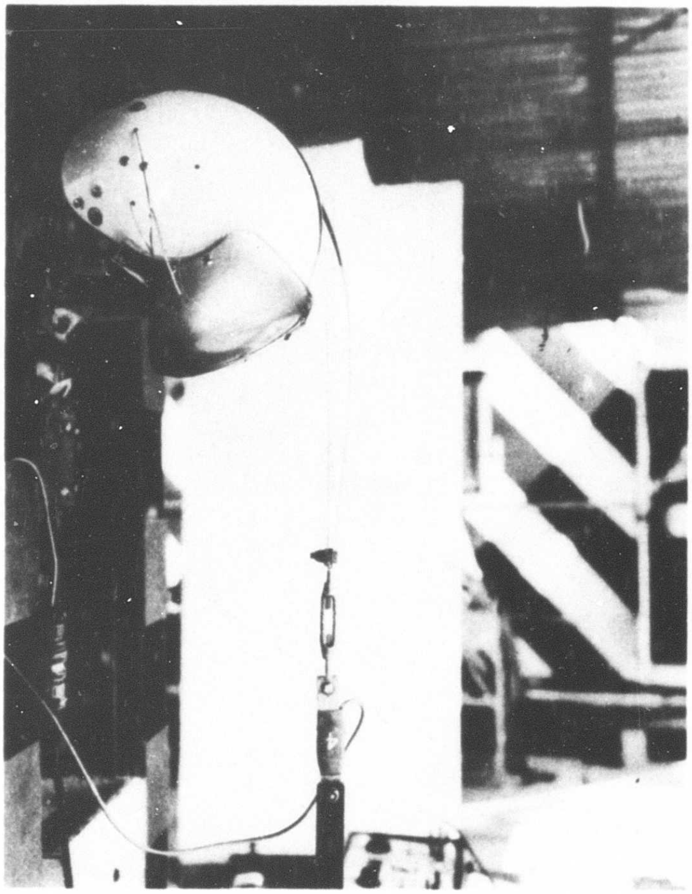

Figure 20. Test Setup for Test No. 1 - Loading Parallel to Helmet Crown.

TEST RESULTS

Test No. 1 - Loading Parallel to Helmet Crown

A load was applied and the movement of the helmet downward toward the chin was recorded as shown in Figures 20 and 21. No further movement could be measured after the forward edge of the helmet came to rest on the chin of the head form; however, loading was continued and the back of the helmet continued to slide upward over the occipital area until the stretch in the netting material resulted in failure at a 178-pound load.

Test No. 2 - Loading Upward and Forward

A load was applied as diagramed in Figure 21. The movement of the helmet was measured along the surface of the head form as the helmet rotated forward as shown by the Y dimension in Figure 21. Failure occurred in the netting material at a load of 227 pounds, as shown by the load deformation plot in Figure 21.

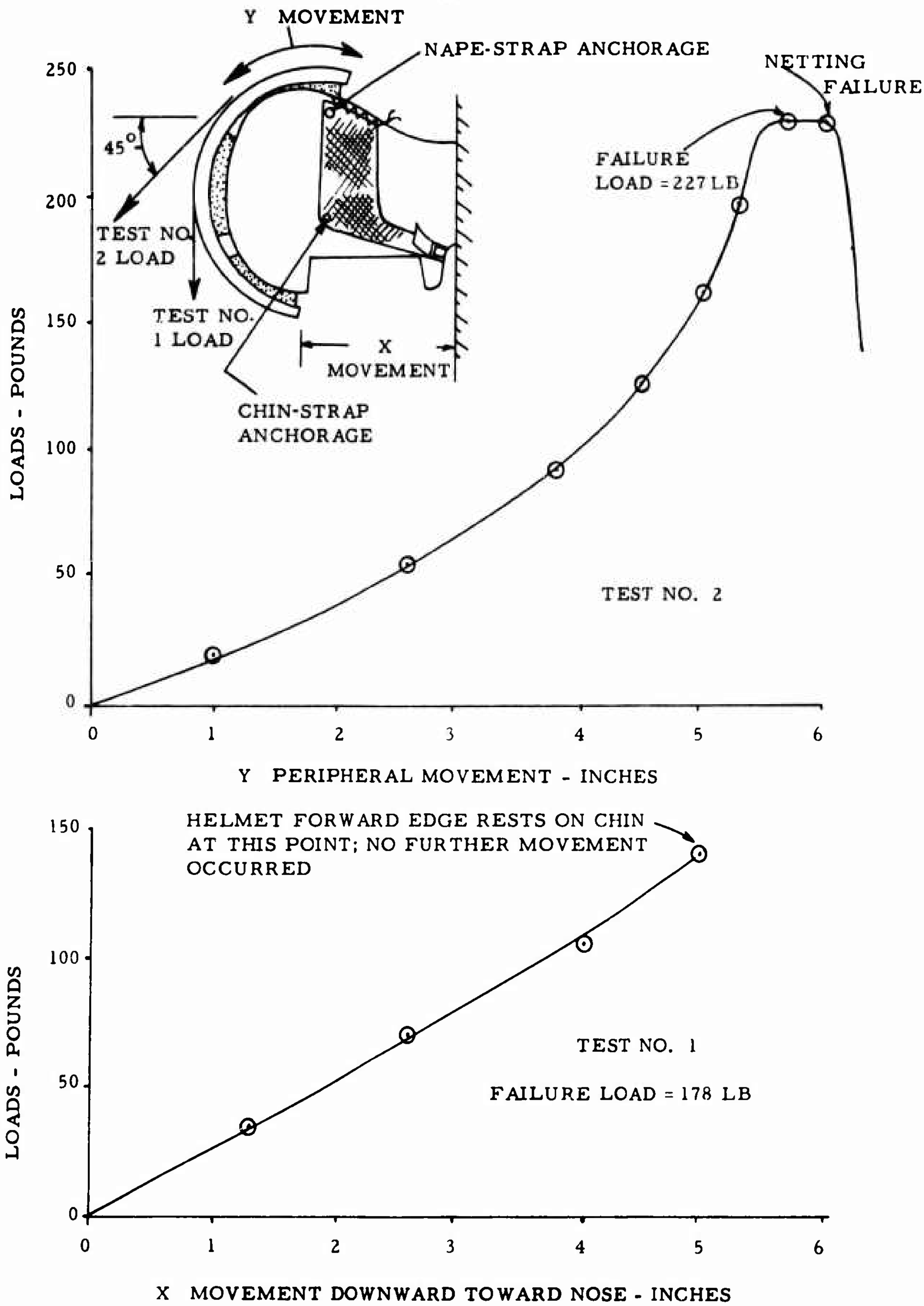

Figure 21. Helmet Movement Recorded for Simulated Helmet Inertia Load.

DISCUSSION OF TEST RESULTS

Neither of the tests resulted in the failure of the dot fastener fitting on the chin strap, whereas this same type of fitting has failed in two instances during dynamic acceleration tests in which helmets were installed on anthropomorphic dummies.

It is concluded that a helmet, with the subject retention harness installed, can be removed from a smooth metal head form under a load of about 200 pounds.

It is recommended that the retention harness be reinforced to carry a load approximately two and one-half times as great as the failure loads recorded.

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DOCUMENT CONTROL DATA - R&D			
(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)			
1 ORIGINATING ACTIVITY (Corporate author) Aviation Safety Engineering and Research 2641 E. Buckeye Road Phoenix, Arizona 85034		2a REPORT SECURITY CLASSIFICATION Unclassified; 2b GROUP	
3 REPORT TITLE Impact Test Methods and Retention Harness Criteria for U. S. Army Aircrewman Protective Headgear			
4 DESCRIPTIVE NOTES (Type of report and inclusive dates) Final Technical Report			
5 AUTHOR(S) (Last name, first name, initial) Haley, J. L., Jr. Turnbow, J. W. Ph.D.			
6 REPORT DATE March 1966	7a TOTAL NO OF PAGES 45		7b NO OF REFS 8
8a CONTRACT OR GRANT NO DA 44-177-AMC-254(T) b PROJECT NO Task 1P125901A14230 c d	9a ORIGINATOR'S REPORT NUMBER(S) USAAVLABS Technical Report 66-29		
	9b OTHER REPORT NO(S) (Any other numbers that may be assigned this report) AvSER 65-15		
10 AVAILABILITY LIMITATION NOTICES Distribution of this document is unlimited.			
11 SUPPLEMENTARY NOTES	12 SPONSORING MILITARY ACTIVITY U. S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia 23604		

13 ABSTRACT

This report discusses impact test methods and helmet retention harnesses for U. S. Army aircrew protective helmets. On the basis of simple analyses and some experimental testing, recommendations are made for the design and testing of helmet retention harnesses. A "collar-type" retention harness is recommended, and two tests are suggested as a method of insuring a good design. Impact tests were conducted by an impactor-drop method and a head-form drop method. These test methods employ one movable piece and one fixed piece rather than two movable pieces as are currently used by most test agencies. On the basis of the impact test results, it is recommended that the impactor-drop method be used for the qualification of U. S. Army aircrew helmets. Probable head impact velocities and impact surfaces are discussed, and impact test conditions are specified.

DD FORM 1 JAN 64 1473
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14. KEY WORDS	LINK A		LINK B		LINK C	
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